The IDEA Drift Chamber for a Lepton Collider
Letter Of Interest for Snowmass 2021

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Abstract

The IDEA detector concept is intended for both the FCC-ee collider, proposed to be built at CERN, and the CEPC collider, proposed to be built in China. It is described in detail in the respective Conceptual Design Reports [1] [2].

The IDEA drift chamber (DCH) is designed to provide efficient tracking, high precision momentum measurement and excellent particle identification by exploiting the application of the cluster counting technique.

Main peculiarities of this drift chamber are its high transparency, in terms of radiation lengths, obtained thanks to the novel approach adopted for the wiring and assembly procedures. The total amount of material in radial direction, towards the barrel calorimeter, is of the order of $1.6\%\,X_0$, whereas in the forward and backward directions it is equivalent to about $5.0\%\,X_0$, including the endplates instrumented with front end electronics. The high transparency is particularly relevant for precision electroweak physics at the Z pole and for flavour physics, where the average charged particles momenta are in a range over which the multiple scattering contribution to the momentum resolution is significant.

Particle identification is particularly relevant for b and c physics, for spectroscopy studies at the Z-pole, for flavour-tagging jets, for the search of lepton flavour violating Z decays and for separating pions from kaons in tau final states. The cluster counting technique offers a unique opportunity of improving the best attainable resolution in energy loss measurement by more than a factor 2, down to $\sim$2%.

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The IDEA DCH design stems from the original ancestor drift chamber of the KLOE experiment[3], recently culminated in the construction of the MEG II[4] drift chamber.

The DCH is a unique volume, high granularity, all stereo, low mass cylindrical drift chamber, co-axial to the $2\,T$ solenoid field. It extends from $35\,cm$ inner radius to $2\,m$ outer radius, for $4\,m$ length and consists of 112 co-axial layers, at alternating sign stereo angles (in the range from $50\,mrad$ to $250\,mrad$), arranged in 24 identical azimuthal sectors. The square cell size (5 field wires per sense wire) varies between 12.0 and $14.5\,mm$ for a total of 56,448 drift cells. Thanks to the peculiar design of the wiring procedures, successfully applied to the recent construction of the MEG II drift chamber, such a large number of wires poses no particular concern.

A system of tie-rods directs the wire tension stress to the outer endplate rim, where a cylindrical carbon fibre support structure, bearing the total load, is attached. Two thin carbon fibre domes enclose the gas volume. Their profile is suitably shaped in order to minimise the stress on the inner cylindrical wall, and they are free to deform under gas pressure variations, without affecting the wire tension.

The angular coverage, for infinite momentum tracks originated at the interaction point and efficiently reconstructed in space, extends down to approximately 13° polar angle.

In order to facilitate track finding, the sense wires are read out from both ends to allow for charge division and time propagation difference measurements.

The chamber is operated with a very light gas mixture, $90\%He - 10\%iC_4H_{10}$, corresponding to about $400\,ns$ maximum drift time for the largest cell size. The number of ionisation clusters (dN_{cl}/dx) generated by a $m.i.p.$ in this gas mixture is $\sim$12.5 cm^{-1}, allowing for unambiguous exploitation of the cluster counting/timing techniques for improving both spatial resolution ($\sigma_{xy} < 100\,\mu m$ expected) and particle identification ($\sigma(dN_{cl}/dx)/(dN_{cl}/dx)$ $\sim$2%).

A $100\,\mu m$ drift distance resolution, averaged over all drift times, has been measured in different $7\,mm$ cell prototypes of the MEG2 drift chamber[5] with very similar electrostatic configuration and gas mixture. For DCH we expect an even lower resolution, less affected by the ionisation statistics, because of the larger average drift distances. Analytical calculations, limited exclusively to the DCH measured space points, for the expected transverse momentum and angular resolutions are plotted in Figure 1 (left). In addition, the application of the cluster timing technique will further improve the resolutions.

Based on the assumption that one can, in principle, reach a relative resolution on the measurement of the number of primary ionisation clusters, N_{cl}, equal to $1/\sqrt{N}_{cl}$, the expected performance relative to particle separation in number of units of standard deviations is presented in Figure 1 (right) as a function of the particle momenta. Solid curves refer to cluster counting technique applied to a $2\,m$ track length with 80% cluster identification efficiency and negligible (a few percent) fake clusters contamination. Dashed curves refer to the best theoretical prediction attainable with the dE/dx technique for the same track length and same number of samples. For the whole range of momenta, particle separation with cluster counting outperforms dE/dx technique by more than a factor of two, estimating an expected pion/kaon separation of better than three standard deviations for all momenta below $850\,MeV/c$ and from slightly above $1.0\,GeV/c$ up to a few hundreds GeV/c. Undoubtledy, such analytical projections need to be fully validated by detailed Montecarlo simulations and by experimental tests at dedicated beams. Both these topics constitute the compelling research program of the immediate future.

For the purpose of optimising the track reconstruction performance, a vertex detector made of seven cylindrical layers and five forward disks, within the drift chamber inner radius, has been simulated together with a layer of silicon microstrip detectors surrounding the drift chamber both in the barrel and in the forward regions in a homogeneous $2\,T$ solenoid magnetic field. Details of ionisation clustering for cluster counting/timing analysis have not been included in the simulations.

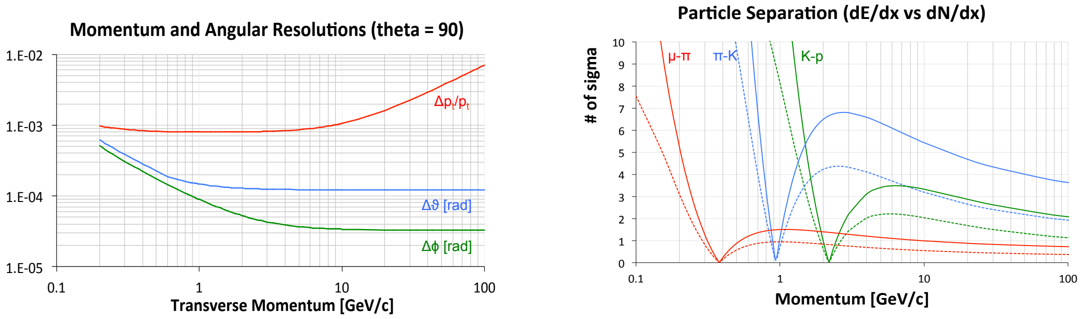

Figure 1: Momentum and angular resolutions as a function of the particle transverse momenta for $\theta = 90°$. $100\,\mu m$ spatial resolution has been assumed (left). Particle separation in terms of numbers of standard deviations, with cluster counting (solid lines) and with dE/dx (broken lines) as a function of the particle momenta. A cluster counting efficiency of 80% and a dE/dx resolution of 4.2% have been assumed (right). Both plots have been obtained with purely analytical calculations limited exclusively to the DCH measured space points.

A simplified track finding algorithm at its preliminary stage of development has been used to feed the space points to the GENFIT2[6] interface for the ultimate track fit. No optimisation has been tried yet. Transverse momentum, impact parameter and polar angle resolutions thus obtained are shown in Figure 2 and compared with analytical calculations. Asymptotic momentum resolution $\delta(1/p_t) < 3 \times 10^{-5}\, GeV/c^{-1}$, longitudinal and transverse impact parameter resolutions of $2\,\mu m$ and polar angle resolution $\Delta\theta < 50\,\mu rad$ are shown to be within reach. Muons from $Z \rightarrow \mu\mu$ can be measured with a relative transverse momentum resolution $\Delta p_t/p_t = 0.0013$.

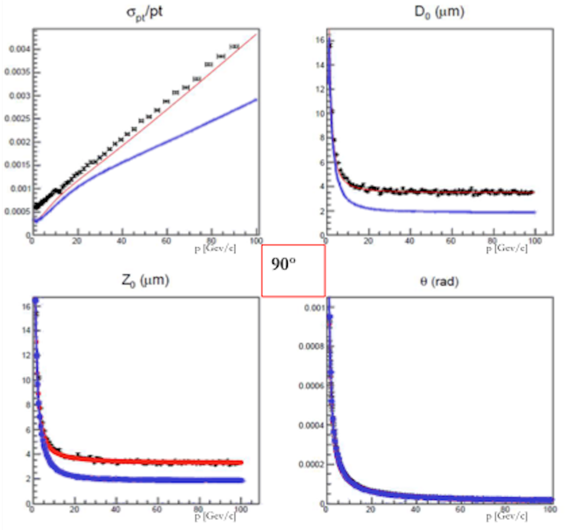

Figure 2: Agreement between full simulation (black dots) and analytical calculations (red curves) in transverse momentum, impact parameter and polar angle resolutions. Blue curves refer to results obtainable with a more aggressive vertex detector resolution.

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